Embodied Emissions

Embodied Greenhouse Gas Emissions in Switzerland:
A case study for the trade with products from the energy and food sector

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Abstract

By international comparison, Switzerland has a relatively low per capita output of greenhouse gas emissions. But the country depends heavily on imports. To obtain a realistic picture of Switzerland's contribution to climate change, the emissions caused by domestic consumption, but originating outside its national boundaries – so-called 'embodied' emissions – must be quantified. In a case study, the embodied emissions due to the trade with products from the energy and foodstuffs sector are analysed using national statistical data and product specific life cycle assessment data, hence combining macro- and microeconomic information. The embodied emissions for 1998 caused by the energy and the foodstuffs sector are equivalent to about 26% and to 8%, respectively, of the total emissions specified in the national greenhouse gas inventory. If rough estimates for other sectors are included, the figure for embodied emissions rises to 70% of the national total. This study illustrates the significance of embodied emissions in the Swiss context.

Suggested key words: climate convention, energy, embodied energy, embodied greenhouse gases, emissions allocation, emissions attribution, export, food, greenhouse gas inventory, greenhouse gas precursors, import, life cycle assessment, Switzerland, UNFCCC

1 Introduction

The United Nations Framework Convention on Climate Change (Climate Convention, UNFCCC) requires its member states to prepare national greenhouse gas inventories on an annual basis (IPCC 1997, LIECHTI 2000). The inventories list the emissions arising within each country's territory (territorial principle). Emissions arising during manufacture and transport of commercial goods are assigned at the point at which they are released to the atmosphere, irrespectively of where the goods are consumed.

The UNFCCC approach allows the emissions to be clearly attributed to individual countries and helps to avoid overlapping entries and gaps in the national inventories. Yet, to obtain the volume of emissions associated with the goods that the people of a country consume, the so-called 'embodied' emissions must be determined based on knowledge about goods exchanges between countries. The balance of these emissions can be added to the 'direct' emissions stated in the national inventories.

The term “embodied” (or “indirect”) energy use (or emissions) has been used by several authors to distinguish the indirect energy uses for the production of goods in contrast to the direct energy uses. VAN ENGELENBURG *et al.* (1994) used the term while investigating the indirect energy uses of households due to the consumption of goods and services. COLEY *et al.* (1997) investigated the *embodied* energy of food products. The term has also been used to investigate the emissions that take place outside a country and which are embodied in products consumed at the place of analysis (e.g. SUBAK 1995). This study focuses on all emissions that take place outside of Switzerland and that are caused due to the Swiss consumption patterns. Emissions within the Swiss boundaries, which are exported with products, are subtracted from the balance. Thus embodied refers to the emissions outside of Switzerland in contrast to the direct emissions within the country. Fig. 1 shows the distinction of *embodied* greenhouse gas emissions released by foreign processes (grey) and *direct* greenhouse gas emissions released by domestic processes (white).

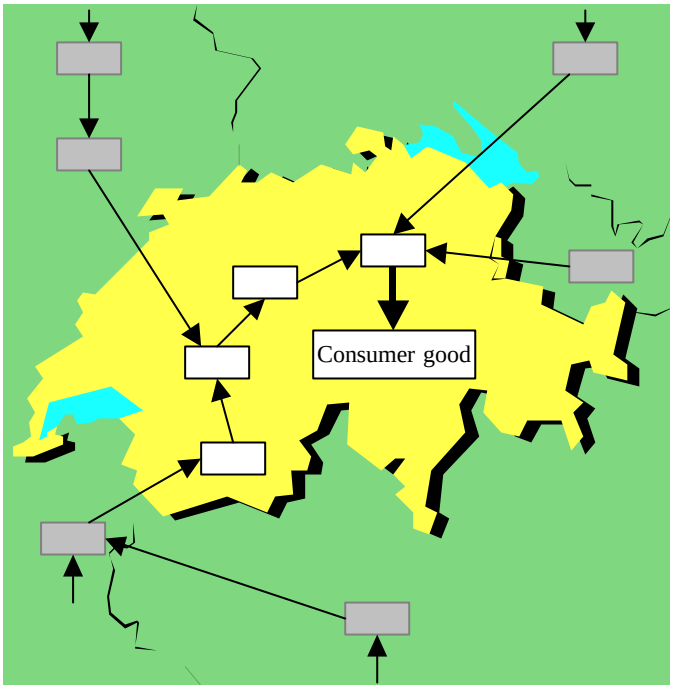

Fig. 1: Distinction of *embodied* greenhouse gas emissions released by foreign processes (grey) and *direct* greenhouse gas emissions released by domestic processes (white) of the life cycle of a consumer good purchased in Switzerland.

2 Goals of the study

Concerning per capita greenhouse gas emissions, Switzerland is in a relatively favourable position compared to other highly industrialised countries. Whereas about 6 tonnes of CO_2 are emitted within Switzerland per person and year, an average of 11 tonnes of CO_2 are emitted in the OECD member states.[1] Switzerland's low emission figure may be attributed primarily to its modest industrial sector and to the fact that its electricity production is largely CO_2-free, because it is mainly based on hydropower and nuclear energy. The low values given in the national greenhouse gas inventory tend to overlook the fact that for the goods that Switzerland must import, sizeable emissions are generated in the producing countries. To a lesser extent, Switzerland is also an exporter of goods, and therefore of corresponding emissions. To obtain a more realistic picture of the emissions that relate to Swiss consumption patterns, the embodied emissions need to be taken into account in interpreting the national inventory of direct emissions.

Policy measures, e.g. CO_2-taxes, might lead to a shift in production and importing patterns of goods. By updating the inventory of embodied emissions at intervals, the shifts in emissions due to changing export and import patterns may be followed and analysed, and the possible need for additional action to achieve the intended benefits for the global climate system may be identified.

Inventories of embodied greenhouse gas emissions resulting from Switzerland's foreign trade in the years 1990 and 1998 (incl. greenhouse gas precursors and SO_2) are presented in this paper based on a recently published study (FRISCHKNECHT & JUNGBLUTH 2000).[2] In earlier estimates, the special relevance of the energy[3] and foodstuffs sectors was recognised (BIEDERMANN *et al.* 1992) and for products in these sectors, comprehensive up-to-date life cycle assessment (LCA) data are now available (FRISCHKNECHT *et al.* 1996, JUNGBLUTH 2000). These sectors were therefore chosen for a detailed analysis.

To obtain a comprehensive picture of greenhouse gas emissions in Switzerland, the present study also provides an estimate for other sectors so far not investigated in detail. This permits earlier studies on the significance of embodied emissions to be corroborated, and indicates those areas needing more analysis. Furthermore, useful experience relevant to the eventual re–allocation of certain emissions in the context of the Climate Convention may be gained in assessing the methodological problems connected with data acquisition and emissions attribution.

3 Method

The present study is based on data on the quantity of products sold in Switzerland and those traded with other countries (branch and foreign trade statistics) (FRISCHKNECHT & JUNGBLUTH 2000). The greenhouse gas emissions are quantified for a range of products (per kg, kWh, etc.) using the method of life cycle assessment.[4] Background databases for energy systems (FRISCHKNECHT *et al.* 1996) and food consumption (JUNGBLUTH 2000, JUNGBLUTH *et al.* 2000) could be used in order to determine emission factors for a range of products. In the energy and foodstuffs sectors, the greenhouse gas inventories for imported products comprise all production processes occurring abroad that add to the value of the product (see also Fig. 1). By this means, prior emissions resulting, for example, from energy consumption during the production process, may be identified and related to domestic emissions. The following chapters explain the system definition and system boundaries for the calculation of emission factors in the two sectors.

3.1 Energy sector

The “energy sector” refers in this context to the trade with energy resources (e.g. crude oil, natural gas, uranium), fuels (gasoline, gas, coal, etc.) and electricity. The sector is classified according to the national greenhouse gas inventory based, for its part, on the provisions of the Climate Convention. In certain cases, the embodied emissions were assigned to suitable categories by analogy. This concerns particularly

electricity trading and the production of nuclear fuels (here, no greenhouse gas emissions arise in Switzerland), and the export of petroleum products (BFE 1991a, b, 1999a, b).

In the case of petroleum products traded in the energy sector, exploration, production and long-distance transport via pipeline, oil tanker, rail and road are taken into account. Emissions from refineries abroad are also included. On the other hand, the emissions from Swiss refineries have not been included, since these are already contained in the national inventory.

The pattern of foreign trade in energy resources is modelled based on economic considerations. The power mix applicable to the electricity sold in Switzerland and exported abroad comprises both electricity acquired abroad and that produced inland (see Fig. 2).

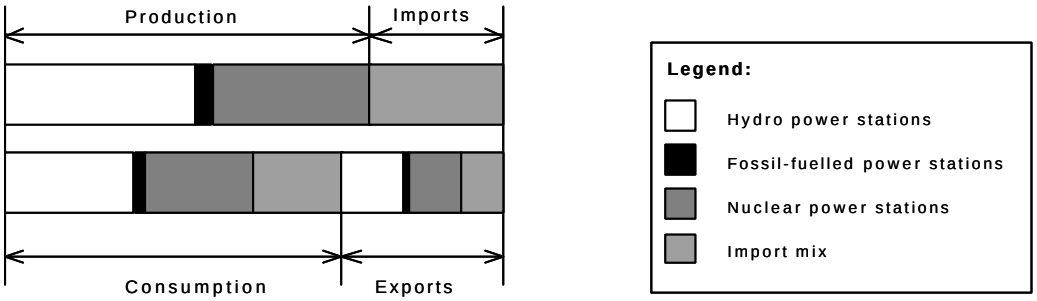

Fig. 2: Electricity model used in this study. Diagram based on Ménard *et al.* (1998:p.10,11). The mix of domestic production plus the mix of imports is assigned to the use of electricity for consumption and exports.

3.2 Foodstuffs sector

The foodstuffs sector includes the imports and exports of means of production (e.g. fertilizers, machinery, etc.), agricultural products (e.g. fodder, meat, vegetables, etc.) as well as for processed food (e.g. vine, pasta, etc.). For the foodstuffs sector, a comprehensive inventory has been prepared containing the embodied emissions associated with the production, processing and transport of foodstuffs. The classification adopted in the national greenhouse gas inventory could not be applied here, so that the embodied greenhouse gas emissions had to be quantified independently. Instead, the classification adopted in the overall foreign trade statistics of the Swiss Farmers' Union was used (SCHWEIZERISCHER BAUERNVERBAND 1991, 2000).

In a first step factors are calculated in an LCA that give the emission of CO_2, CH_4, N_2O, NO_x, CO, NMVOC and SO_2 per kg for a range of products (e.g. tomatoes, vegetables, etc.) that belong to the foodstuff sector. Emission factors for vegetables, meat, animals, animal fodder, cereals and means of production, could be directly taken from a case study for food consumption (JUNGBLUTH 2000). Emission factors for further

products have been calculated using the simplified modular LCA (JUNGBLUTH *et al.* 2000). The inventory of embodied emissions includes greenhouse gas emissions from agricultural production and food processing, but not from packing materials used or produced outside Switzerland. Their contribution to greenhouse gas emissions can be assumed to be of minor importance for a certain product in comparison to the emissions of foodstuffs production (JUNGBLUTH 2000).

Transports are calculated separately for all food products together based on average data for transport modes and countries of origin given in the foreign trade statistics for Switzerland (EIDG. OBERZOLLDIREKTION 1990, 1998) and LCA data for transport modes (MAIBACH *et al.* 1995). These emissions are included in the total balance for the foodstuff sector.

4 Results

4.1 Results for the energy sector

Tab. 1 shows the results for the energy sector according to the IPCC source categories. The embodied greenhouse gas emissions for the energy sector in 1990 amounted to about 12 500 Gg CO_2-eq.[5] By 1998 they had risen to 13 700 Gg CO_2-eq. The main reasons for the increase are the rise in electricity trading and in purchases of natural gas. Tab. 1 shows also the detailed figures embodied emissions of single greenhouse gasses in 1998.

Tab. 1: Embodied greenhouse gas emissions in Gg and Gg CO_2-eq respectively for the IPCC source categories of the Swiss energy sector in 1990 and 1998.

IPCC-category	in Gg (= 1'000'000kg)	1990	1998			
		CO_2-eq	CO_2-eq	CO_2	CH_4	N_2O
1.A.	Energy (combustion)	12'504	13'691	11'999	77.7	0.19
1.A.1	Energy conversion	4'768	5'691	5'393	13.6	0.04
1.A.2.	Industry	779	816	600	10.1	0.01
1.A.3.	Transport (incl. military aviation)	3'599	3'644	3'166	21.8	0.06
1.A.4.	Commercial, institutional, residential	3'210	3'397	2'721	31.2	0.07
1.A.5.	Others (Building machinery, military)	148	142	119	1.07	0.00
1.B.	Fugitive emissions	0.0	0.0	0.0	0.0	0.00
1.C.	International Bunkers	536	723	597	5.77	0.02

The analysis of the energy sector in Fig. 3 shows that the largest portion of embodied greenhouse gas emissions is attributable to the import of petroleum products. Of almost comparable magnitude are the embodied emissions arising from electricity trading. This applies particularly to 1998. Owing to a rise in this

business activity on the part of the Swiss utilities, their share had increased in 1998 not only in relative, but also in absolute terms.

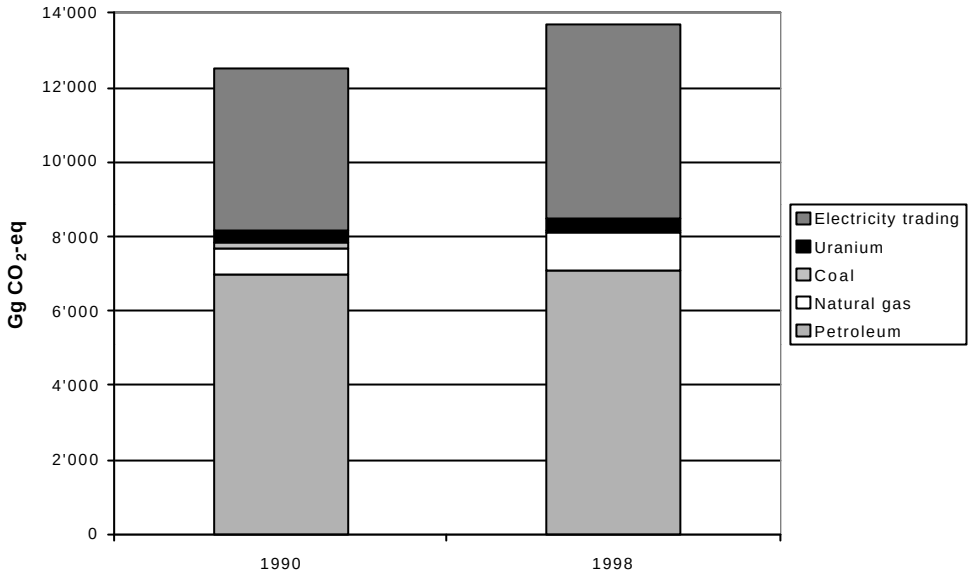

Fig. 3: Embodied greenhouse gas emissions in the energy sector in Switzerland in 1990 and 1998.

The embodied greenhouse gas emissions from the production of natural gas are becoming increasingly important. This is attributable to the heavy increase in domestic sales in Switzerland. The production of nuclear fuel (uranium) and coal contribute very little to the total embodied greenhouse gas emissions.

For Switzerland, the inclusion of embodied emissions from the energy sector results in an increase of almost 24% for 1990, or almost 26% for 1998, with respect to the gross emissions stated in the national greenhouse gas inventory. Fig. 4 shows that for 'energy conversion', the share of embodied emissions is over proportional. This is explained by the very limited refinery and combustion activities taking place in the Swiss energy sector and the important role of electricity trading with neighbouring countries.

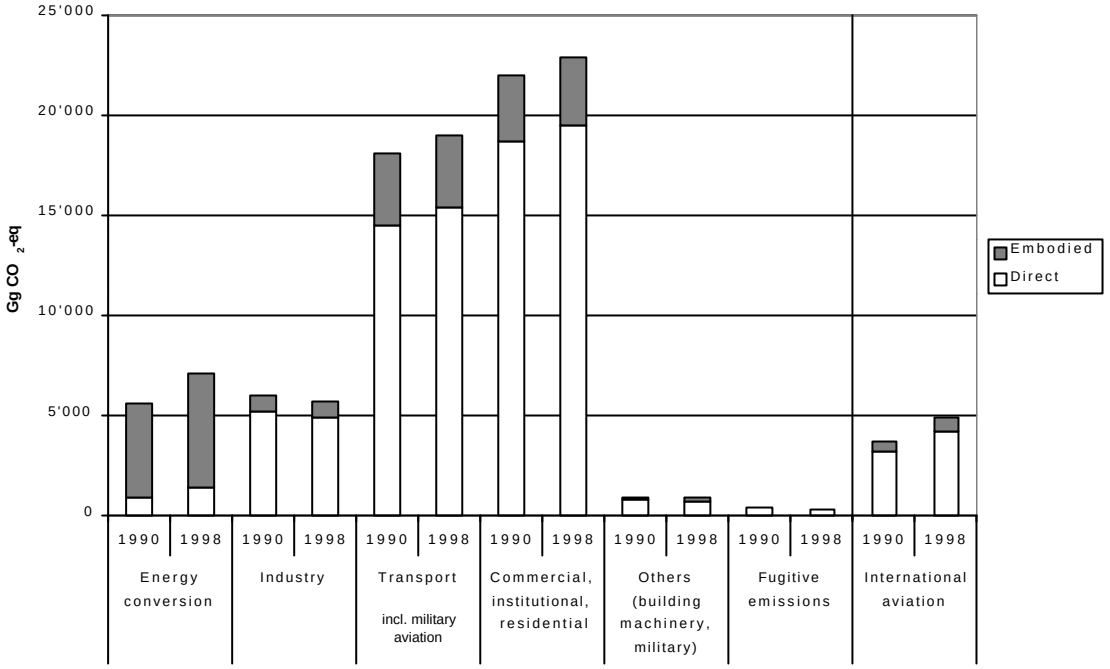

Fig. 4: Direct and embodied greenhouse gas emissions in the energy sector in Switzerland according to IPCC source categories, 1990 and 1998. Emissions from international aviation are not included in total figures for Switzerland.

The embodied emissions of NMVOC and SO_2, are of comparable magnitude to the inland emissions, and may even exceed these (see Fig. 5). In general, total precursor and SO_2 emissions within Switzerland decreased between 1990 and 1998 due to stricter environmental regulations including lower emission limits. Embodied emissions kept nearly constant or increased slightly (NO_x, SO_2). The high shares of embodied NMVOC and SO_2 emissions stem from oil and gas production sites (venting of gases) and long distance transportation of crude oil with tankers fuelled with heavy fuel oil with a high sulphur content (about 3.5 wt.-%).

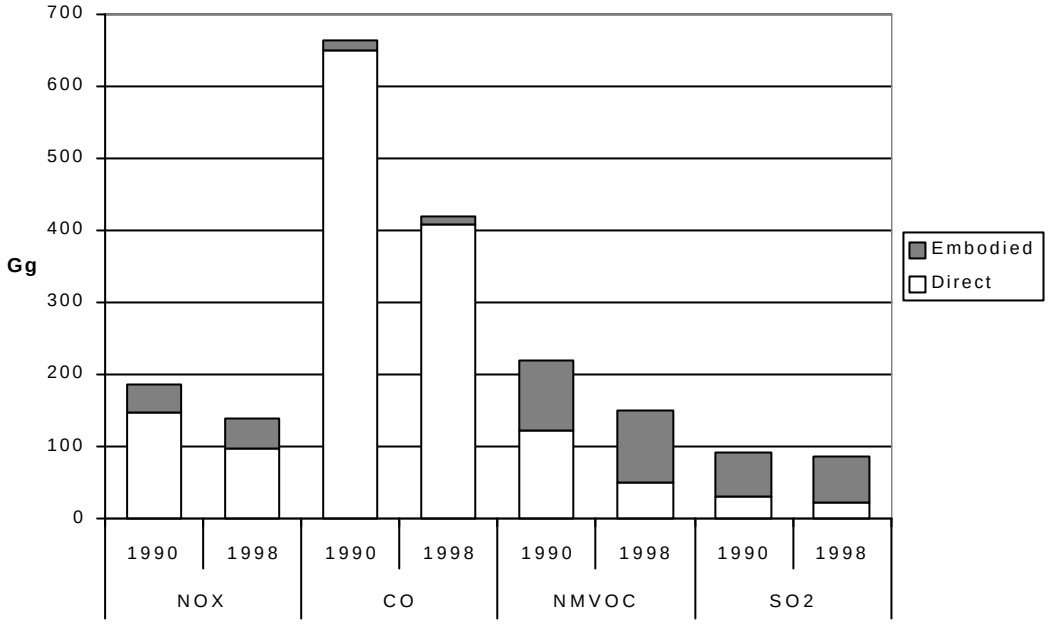

Fig. 5: Direct and embodied emissions of precursor substances and SO_2 for the energy sector in 1990 and 1998.

4.2 Results for the foodstuffs sector

For approximately 80% of imported and exported agricultural products, relatively precise emission factors could be determined from LCA studies ('safe' scenario). For the remaining products, an estimate based on analogy was made ('extended' scenario).

In the foodstuffs sector, the import balance for embodied greenhouse gases is clearly positive, amounting to upwards of 4300 Gg CO_2-eq per annum. Fig. 6 shows the embodied greenhouse gas emissions for the years 1990 and 1998 for the 'extended' scenario. Tab. 2 shows the detailed figures for all embodied greenhouse gas emissions in 1998. Only in the case of products of animal origin are the exports (notably cheese) of comparable magnitude to imports. In total, both imports and exports declined slightly between 1990 and 1998. While there was a decrease for the means of production (i.e. fertilizer) and transports, the figures for fruits and vegetables increased.

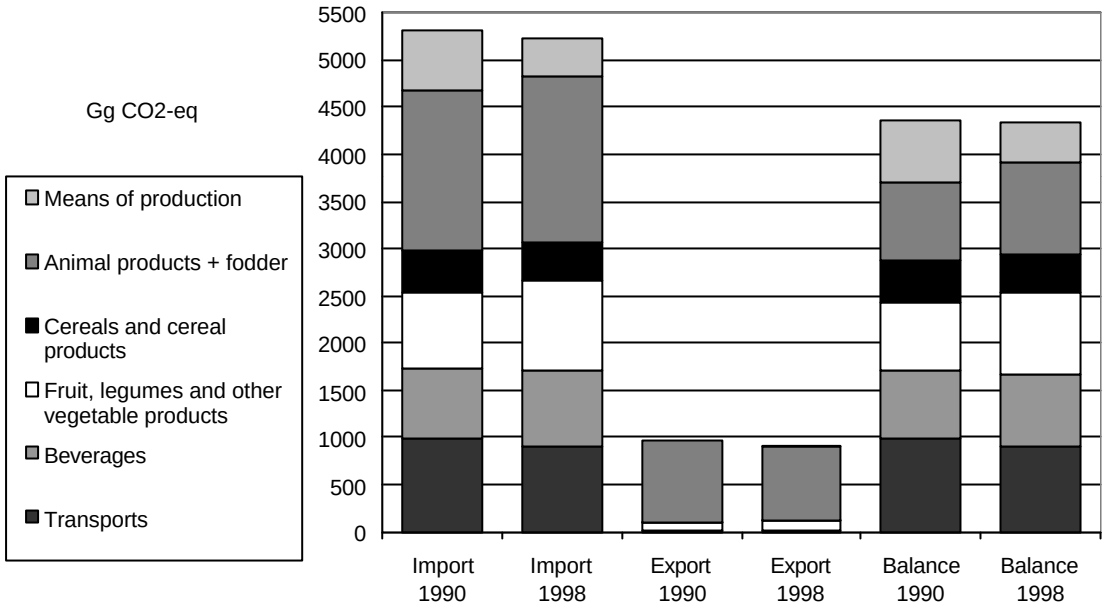

Fig. 6: Embodied greenhouse gas emissions in the foodstuffs sector based on imports and exports for 1990 and 1998. All data are based on the 'extended' scenario.

Tab. 2: Embodied greenhouse gas emissions in Gg and Gg CO2-eq for the foodstuffs sector based on imports and exports for 1998. All data are based on the 'extended' scenario.

	Import				Export				Balance
"Extended" scenario 1998 in Gg	**CO_2**	**CH_4**	**N_2O**	**CO_2-eq**	**CO_2**	**CH_4**	**N_2O**	**CO_2-eq**	**CO_2-eq**
Means of production	394.3	1.1	0.0	419.2	5.6	0.0	0.0	5.9	413.3
Animal products + fodder	388.9	37.6	1.8	1743.2	160.5	18.4	0.7	766.3	976.9
Cereals and cereal products	148.2	3.8	0.6	419.9	1.9	0.0	0.0	4.3	415.6
Fruit, legumes and other vegetable products	605.4	6.4	0.7	949.6	45.0	1.2	0.1	98.8	850.8
Beverages	499.6	1.5	0.9	808.0	14.6	0.0	0.0	25.9	782.0
Transports	860.4	1.4	0.0	895.4	-	-	-	-	895.4
Total	**2896.8**	**51.7**	**4.0**	**5235.4**	**227.7**	**19.7**	**0.8**	**901.3**	**4334.1**

Tab. 3 lists the absolute emissions of precursor substances (NO_x, CO, NMVOC) and SO_2. Animal products, i.e. cheese, are important for the exports while transports of food products have the largest share for imports. Emissions within Switzerland due to the transport of exported goods are not included in this calculation. Imports of embodied emissions are much higher than exports.

Tab. 3: Embodied emissions of precursor substances and SO_2 in the foodstuffs sector based on imports and exports for 1998 in Gg. All data are based on the 'extended' scenario.

	Import				Export			
"Extended" scenario 1998 in Gg	**NO_x**	**CO**	**NMVOC**	**SO_2**	**NO_x**	**CO**	**NMVOC**	**SO_2**
Means of production	1.19	1.54	0.62	1.65	0.03	0.02	0.02	0.03
Animal products + fodder	3.02	1.16	1.11	1.44	1.08	0.39	0.40	0.54
Cereals and cereal products	0.94	0.41	0.38	0.43	0.01	0.00	0.00	0.01
Fruit, legumes and other vegetable products	2.21	0.96	1.49	1.24	0.20	0.07	0.09	0.11
Beverages	3.83	1.67	1.65	2.76	0.13	0.06	0.05	0.07
Transports	7.38	3.17	3.05	2.64	-	-	-	-
Total 1998	**18.57**	**8.91**	**8.30**	**10.16**	**1.45**	**0.55**	**0.57**	**0.75**

4.3 Results for other sectors and travelling

A rough estimate of greenhouse gas emissions has been made for further sectors (e.g. chemicals, vehicles, etc.) and product segments so far not included in the analysis. It is based on emission factors for some typical products from these sectors and statistical data for imports. This estimation leads to additional approx. 20 000 Gg CO_2-eq of embodied emissions. Of this, over 5000 Gg are attributable to chemical products, about 3500 Gg each to the segments 'iron, steel and non-ferrous metals' and 'data processing and computers', and some 1500 Gg to vehicle imports. The transport of these imported goods into Switzerland, which has been investigated in the same manner as for foodstuff, contributes another 5000 Gg CO_2-eq.

A recent study by Kaufmann *et al.* (2000) on air travel of Swiss citizens has concluded, that CO_2 emissions due to international journeys amount to about 6300 Gg in 1999. In this figure direct emissions from international bunkers of some 4200 Gg CO_2 (for 1998) are included, which are, until now, not fully integrated in the national inventories. Thus, the net additional direct emissions by air transport are about 2100 Gg CO_2. When adding the related embodied emissions some 2400 Gg CO_2-eq are reached, corresponding to more than 0.3 tonnes per capita. This example demonstrates that direct and embodied emissions due to international travel generated by a country's citizens may be quite relevant in size. To be fully comprehensive from a "polluter pays" point of view, they would need to be included in the overall emissions balance and assessed against the emissions generated by foreign tourists as customers of the national tourism sector.

4.4 Total balance

Tab. 4 shows the total balance of direct emissions in Switzerland according to IPCC categories (greenhouse gas and precursor substances) and of embodied emissions of the energy and foodstuff sectors calculated in this study for 1998. When embodied emissions from the energy and foodstuffs sectors are included, greenhouse gas emissions in Switzerland rise by 18 000 Gg to over 71 000 Gg CO_2-eq. in 1998. The comparison of the embodied emissions with direct emissions in Switzerland in Tab. 4 indicates that embodied emissions are especially important with regard to SO_2.

Tab. 4: Total balance of direct emissions in Switzerland according to IPCC categories (greenhouse gases and precursor substances) (LIECHTI 2000) and of embodied emissions of the energy and foodstuff sectors in 1998.

Total balance 1998	**Greenhouse gases**				**Precursor substances and SO_2**			
	CO_2	**CH_4**	**N_2O**	**CO_2-eq**	**NO_X**	**CO**	**NMVOC**	**SO_2**
1. Energy	41 211	18	2.25	42 297	99	419	58	21.9
2. Industrial Processes	2204	0.42	0.31	2310	0.321	11	8	3.3
3. Solvent and Other Product Use	0	0.00	0.39	120	0.044	0.088	107	0.037
4. Agriculture	0	139.5	8.33	5512	0.00	0.00	0.00	0.00
5. Land-Use Change and Forestry	-6109	0	0	-6109	0.00	0.00	0.00	0.00
6. Waste	1394	64	0	2827	5.5	3.85	1.4	2.3
7. Other	0	0	0	0	0	0	0	0
Total direct	**38 700**	**222**	**12**	**46 957**	**105**	**433**	**175**	**27.6**
Embodied net emissions energy sector	11999	78	0.19	13 692	40	13	100	65.2
Embodied net emissions foodstuff sector	2669	32	3.20	4334	17	8	8	9.4
Total (direct + embodied)	**53 369**	**332**	**15**	**64 982**	**162**	**455**	**282**	**102.2**

The rough estimate of embodied emissions for all further sectors leads to an additional approx. 20 000 Gg CO_2-eq. Fig. 7 summarises the direct and embodied contributions to the total for the year 1998. For Switzerland, total emissions in the energy sector increase by some 26% when embodied emissions are taken into account. The foodstuffs sector contributes a further 8 %, so that in total, the volume of emissions is increased by more than a third. When embodied emissions in those sectors and product groups that were only roughly quantified are included, total emissions amount to some 70% over and above those quoted in the national inventory.

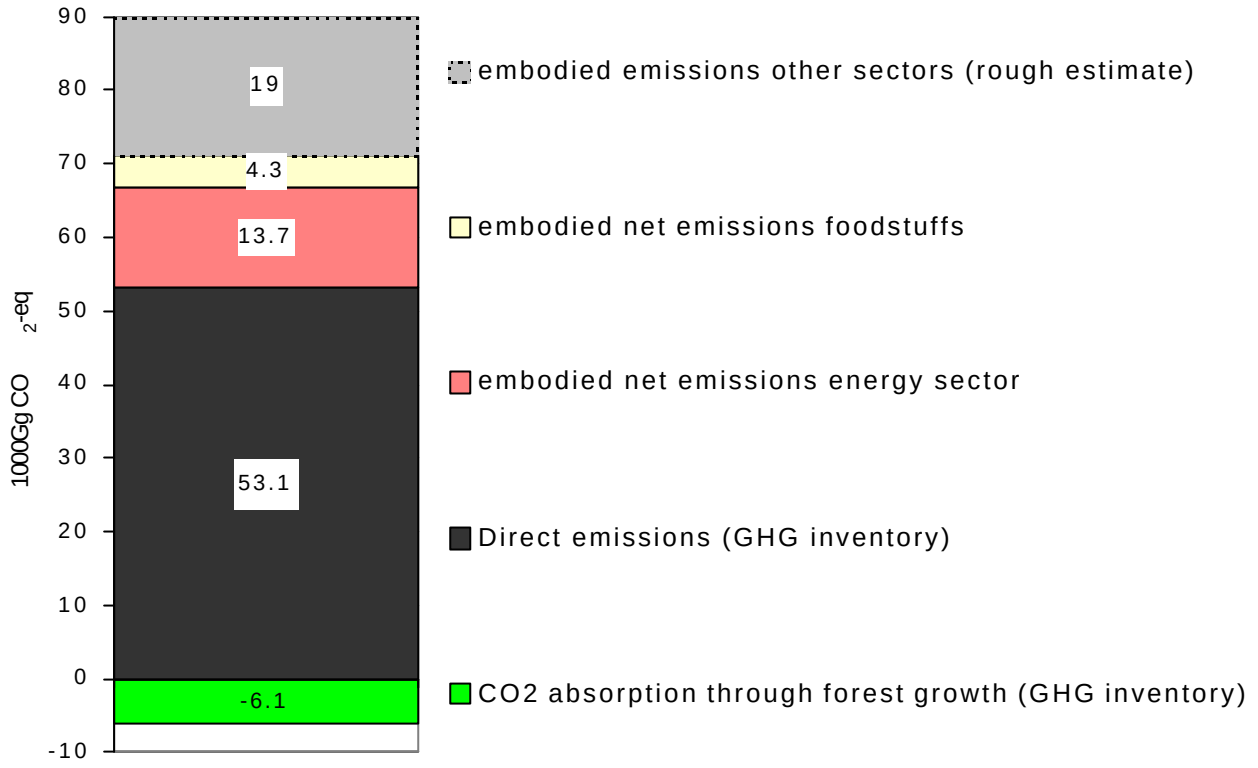

Fig. 7: Total balance of direct and embodied greenhouse gas emissions (GHG) in Switzerland (excl. HFC, PFC, SF6), 1998.

In addition to the direct and embodied emissions, a comprehensive inventory would need to consider those sectors in which emissions are sequestered or reduced. In these, some 6100 Gg CO_2 were taken up from the atmosphere in 1998 resulting from biomass growth in Swiss forests. Additionally, 'exported' emissions can be subtracted for those sectors with a positive export balance. This applies particularly to the chemical industry, textiles, machines, banks and insurance. However, there exist at present too little data to quantify the 'exported' emissions in these sectors. In addition, emissions due to travelling abroad and tourism should be included in the total national inventory.

4.5 Per capita emissions

In Switzerland, direct emissions for the principal greenhouse gas, CO_2, are 6.3 tonnes (calculated on the basis of the national inventory in LIECHTI 2000), and, after including embodied emissions of the energy and the foodstuffs sectors, they amount to 8.4 tonnes. Direct per capita emissions of all greenhouse gasses amount to 7.5 tonnes CO_2-eq. When embodied emissions in the energy and foodstuffs sectors are included, these increase to some 10 tonnes CO_2-eq. When the remaining sectors that could only be roughly estimated are included, per capita emissions increase to almost 13 tonnes CO_2-eq.

These figures clearly illustrate that the comparatively low per capita emissions in Switzerland must be reflected when embodied emissions are taken into account. However, a direct comparison with other industrial countries could so far not be made, since emission inventories that systematically present the embodied greenhouse gas emissions were not available for these. It would be advisable to have comparable studies at hand for countries that have relative high trade with products which are known to be relevant for greenhouse gas emissions (e.g. products from the energy or foodstuff sector, basic materials like aluminium or steel).

5 Discussion

When embodied emissions are taken into account in the inventory, significantly higher figures than given in the national greenhouse gas inventory result for Switzerland. The analyses carried out here for the energy and foodstuffs sectors show that an additional 34% of embodied greenhouse gas emissions must be included.

When the remaining product segments that were only roughly estimated are added, the proportion of embodied greenhouse gas emissions is as high as 70% of the direct emissions. To validate this figure, more extensive data on the export and import of chemical products, metals and electronics products, on transport movements associated with their import, and on those product segments with a positive export balance are required. Furthermore, bunker fuels, as presently handled by the Climate Convention give only a very rough idea of emissions related to travel of persons across a country's boundaries.

The study shows that the combination of national statistics' data and product specific LCA-information allows to quantify the embodied greenhouse gas emissions. Due to the availability of background data from life cycle inventory databases, it was possible to quantify all emissions prior to the import to or after the export from Switzerland for two important sectors. The method presented here might also be used to assess the embodied greenhouse gas emissions for other countries that have a comparable high share of imports for consumed goods, or for countries that are assumed to be net exporters of embodied greenhouse gas emissions.

6 Acknowledgments

The financing of the study by the Swiss Agency for the Environment, Forests and Landscape (BUWAL/SAEFL) is gratefully acknowledged.

7 Endnotes

[1] Information on http://www.iwkoeln.de/IWD/I-Archiv/iwd38-99/t38-99-5.htm.

[2] The full report has been published in German by the Swiss Agency for the Environment, Forest and Landscape (SAEFL) as 'Umwelt-Materialien Nr.128'. It can be ordered from docu@buwal.admin.ch

[3] The “energy sector” refers in this context to the trade with energy resources (e.g. crude oil, natural gas, uranium), fuels (gasoline, gas, coal, etc.) and electricity.

[4] This method aims to investigate and quantify all emissions from cradle to grave of a certain product. This comprises also the production of necessary materials and energy carriers in the life cycle.

[5] 1,000 Gg are equal to 1 million tonnes; CO2-eq = CO2 equivalent = weighted sum of the greenhouse gases quantified in this study (CO_2, CH_4, N_2O)

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10 Figures

11 Tables